AfricaGIS 2019

Innovations in Geospatial Technologies for Achieving Sustainable Development Goals in Africa

AFRIGIST

VULNERABILITY ASSESSMENT OF GULLY EROSION USING GEOSPATIAL TECHNIQUES IN BENIN CITY, EDO STATE, NIGERIA

Department of Geographic Information Science, African Regional Institute for Geospatial Information Science and Technology (AFRIGIST), formerly (RECTAS), off Road 1, Obafemi Awolowo University Campus, P. M. B. 5545, Ile-Ife, Osun State, Nigeria.

Deborah B. Alaigba and Osolase E. Ehiremen

INTRODUCTION

- Soil erosion is a worldwide phenomenon which ravages large areas of land particularly in high rainfall (Murck *et. al*, 1996). Soil-gully erosion has been known as one of the major challenges to global environmental and socio-economic sustainability (Noori *et al.*, 2016).

- Erosion has been described as a well-defined water worn channel (Monkhouse and Small, 1978) While, Gully erosion is an advanced stage of rill erosion where surface channels have been eroded to the point where they cannot be smoothened over by normal tillage operations.

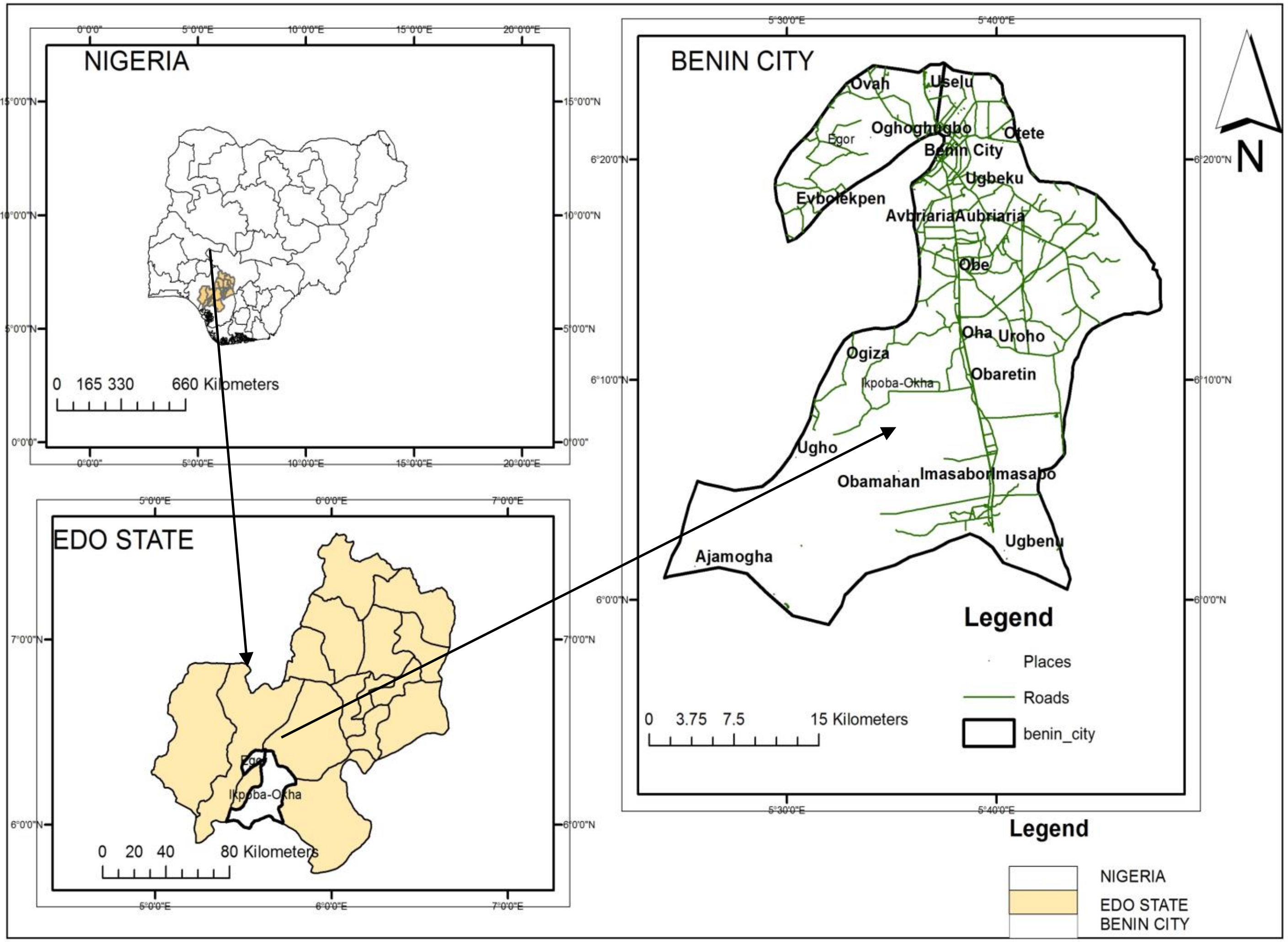
- In Nigeria, the problem of gully erosion has formed a subject for serious consideration since the early 1920s, The major environmental and ecological problems associated with Edo State, a southern state in Nigeria; are waste management, pollution and sanitation, forest depletion, flooding and erosion of the surface of the soil.

- Recently, the introduction of Remote Sensing and GIS technologies and their combination with the empirical models have made soil erosion monitoring more efficient, effective, reliable, faster and easier with sustainable results and low cost (Gelagaya and Minale, 2016; Noori et al., 2016).

- The main objectives of the study are to assess sites vulnerable to gully erosion based on multi-criteria evaluation (MCE) and Analytical Hierarchy Process (AHP).

STUDY AREA

The study area is Benin City. Benin City is located in Southern Nigeria within latitudes 60 20'' 1' N and 60 58'' 1' N and longitudes 50 35'' 1' E and 50 41'' 1' E. It broadly occupies an area of approximately 112.552 km.



Map of study area

METHODOLOGY

SOURCE OF DATA

PRIMARY SOURCE

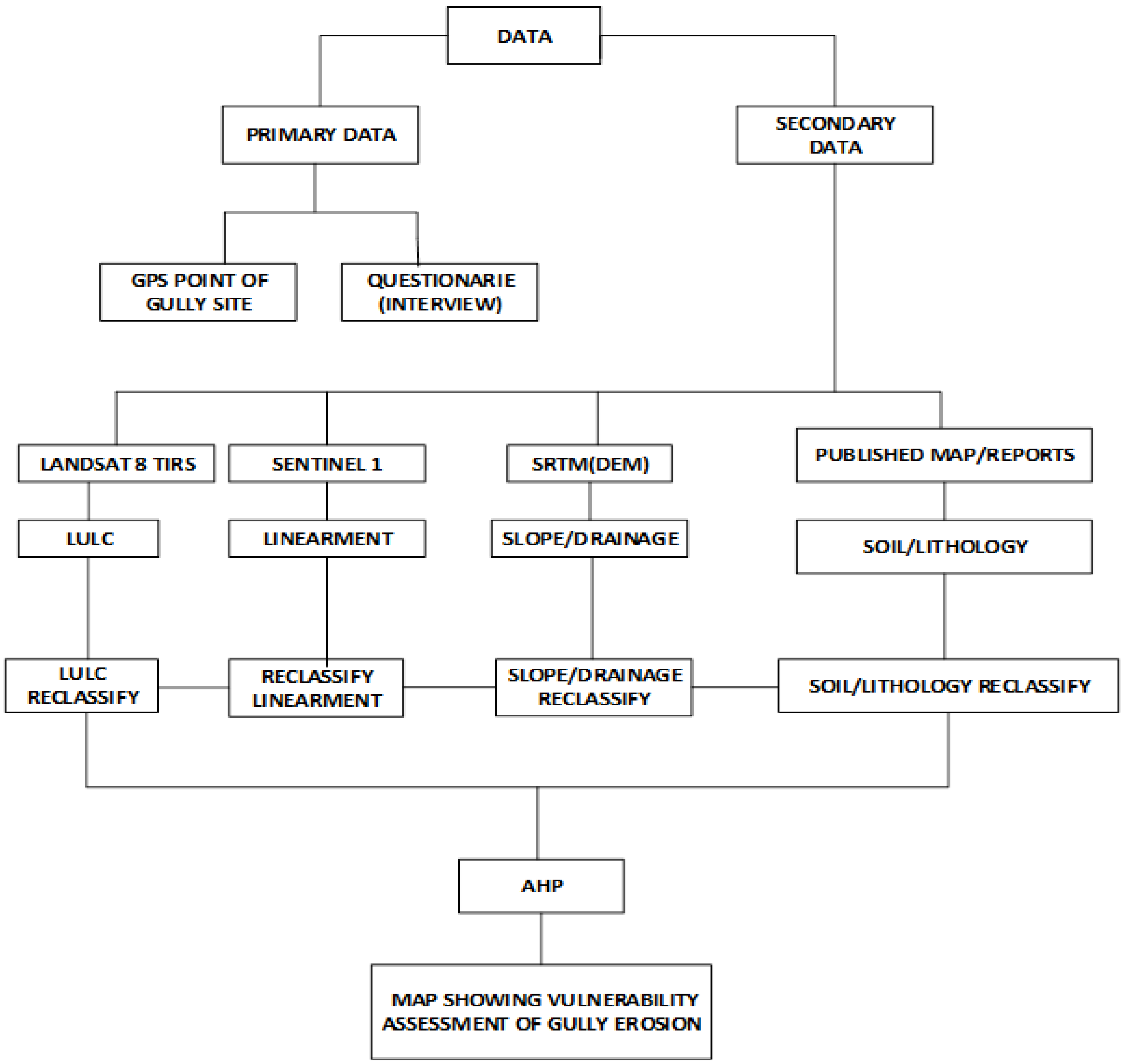
A hand-held GPS device, questionnaire, Field observation, interviews/interaction with residence living close to the gullies.

SECONDARY SOURCE

Soil map, high-resolution imagery obtained from google earth, Sentinel 1 data was downloaded and used for lineament extraction in this study. Digital Elevation Model (DEM) using SRTM was downloaded from Alos palsar for the purpose of slope extraction. Landsat 8 OLI & TIRS was downloaded from Global Land Cover Facility (GLCF) and used in classifying Land use/Landcover (LULC). Snap software was used to analyse the DEM and lineament image, Pci geomatica was used to extract the lineament fractures in the study area, Idrisi was used to create color composites and classify the LULC of the area ArcMap was used to digitize and also for the map layout production.

S/N	DATA TYPE	DATE	SCALE	RESOLUTION	SOURCE
1	High resolution image Sentinel 1(Radar)	2017		10m	Alaska facility
2	Administrative map				Diva.gis.org
3	SRTM AND DEM (Alos Palsat)	2006-2011		12.5m	Alaska facility
4	Soil Map		1:25,000		
5	Landsat 8 (OLI & TIRS)	2018		30m	USGS
6	Lithology Map	2018			NGSA
7	Questionnaire	2018			Self-generated data

WORKFLOW METHODOLOGY



FACTOR METHOD

- The Analytic Hierarchy Process (AHP) is a decision approach designed to aid in the solution of complex multiple criteria problems (Ayalew *et al.* 2004).

- AHP Pairwise Comparison Methods Approach using each sub-class of 3-ranking means of decreasing order of impact (highly vulnerable, vulnerable and less vulnerable) was used to determine risk factor using GIS methods. These factors include Slope, Drainage density, Lineament, lithology, soil and land use/landcover.

DETERMINING THE WEIGHTS OF THE FACTORS USING AHP

INTENSITY OF IMPORTANCE	DESCRIPTION
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance
Reciprocals	Values for inverse comparison

Source: Saaty, 2001

Sample scale for comparison

DEVELOPMENT OF PAIRWISE COMPARISON MATRIX

AFRIGIST

- The Table III shows a pairwise comparison matrix of order 6 where 6 criteria (C1, C2, C3, C4, and C5) are compared against each other. In the direct comparison of the criteria C1 and C2, criterion C1 is regarded equal to moderate importance and similarly relative importance are assigned to the remaining criterion. The transpose position automatically gets a value of the reciprocal; it is 1/5 which equals 0.2.

criteria		Lulu	Lithology	DD	Slope	Soil
		C1	C2	C3	C4	C5
Lulc	C1	1.00	0.33	0.2	0.14	0.11
Lithology	C2	3.00	1.00	0.33	0.2	0.14
DD	C3	5.00	3.00	1.00	0.33	0.2
Slope	C4	7.00	5.00	3.00	1.00	0.33
Soil	C5	9.00	7.00	5.00	3.00	1.00
Total		25.0	16.33	9.53	4.67	1.78

Development of Pairwise Comparison Matrix

NORMALIZED PAIRWISE COMPARISON MATRIX

- In the next step, the assigned preference values are synthesized to determine a numerical value which is equivalent to the weights of the factors. Therefore, the eigen values and eigen vectors of the square preference matrix that show important details about patterns in the data matrix were calculated.

Criteria		LULC	Lithology	DD	Slope	Soil	Row total (c1 to c5)	Priority Vector (row sum/5) Criteria w.	Weight (%)
		C1	C2	C3	C4	C5			
LULC	C1	0.04	0.02	0.02	0.03	0.06	0.17	0.04	3.5
Lithology	C2	0.12	0.06	0.04	0.04	0.08	0.08	0.08	6.8
DD	C3	0.2	0.18	0.11	0.07	0.11	0.67	0.13	13.5
Slope	C4	0.28	0.31	0.32	0.21	0.18	1.3	0.25	26.2
Soil	C5	0.36	0.43	0.52	0.64	0.56	2.5	0.50	50.0
		1.00	1.00	1.00	1.00	1.00	4.72	1.00	100.00

Normalized Pairwise Comparison Matrix

CALCULATING CONSISTENCY RATIO (CR)

- At this stage the consistency ratio (CR) is calculated to measure how consistent the judgments have been relative to large samples of purely random judgments. AHP always allows for some level of inconsistencies which should not exceed a certain threshold (Saaty, 1988)

Criteria		LULC	Lithology	DD	Slope	Soil	Weight criteria sum	Weight criteria	Consistency Ratio (R)
		C1	C2	C3	C4	C5			
LULC	C1	0.04	0.026	0.026	0.04	0.06	0.18	0.04	4.5
Litholog y	C2	0.12	0.08	0.043	0.05	0.07	0.36	0.08	4.54
DD	C3	0.2	0.24	0.13	0.083	0.1	0.75	0.13	5.79
Slope	C4	0.28	0.4	0.39	0.25	0.17	1.5	0.25	5.94
Soil	C5	0.36	0.56	0.65	0.5	0.5	2.82	0.50	5.64
total								26.464	26.464/5 = 5.293

Calculating Consistency Ratio (CR)

➢ The Random inconsistency indices (RI) developed by Saaty was used to determine the consistency ratio (CR), which measures the degree of consistency.

n	2	3	4	5	6	7	8	9	10
R1	0.00	0.52	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Random Indices for matrices of various sizes (Saaty & Vargas,1991)

CR= CI/RI. Where CI=? max-n/n-1, RI=Random consistency index, N=Number of criteria, max is priority vector multiplied by each column total.

CI=? max-n/n-1 =   n = 5

CI=5.293 – 5/5 – 1 = 0.07

n (no. of criteria) = 5

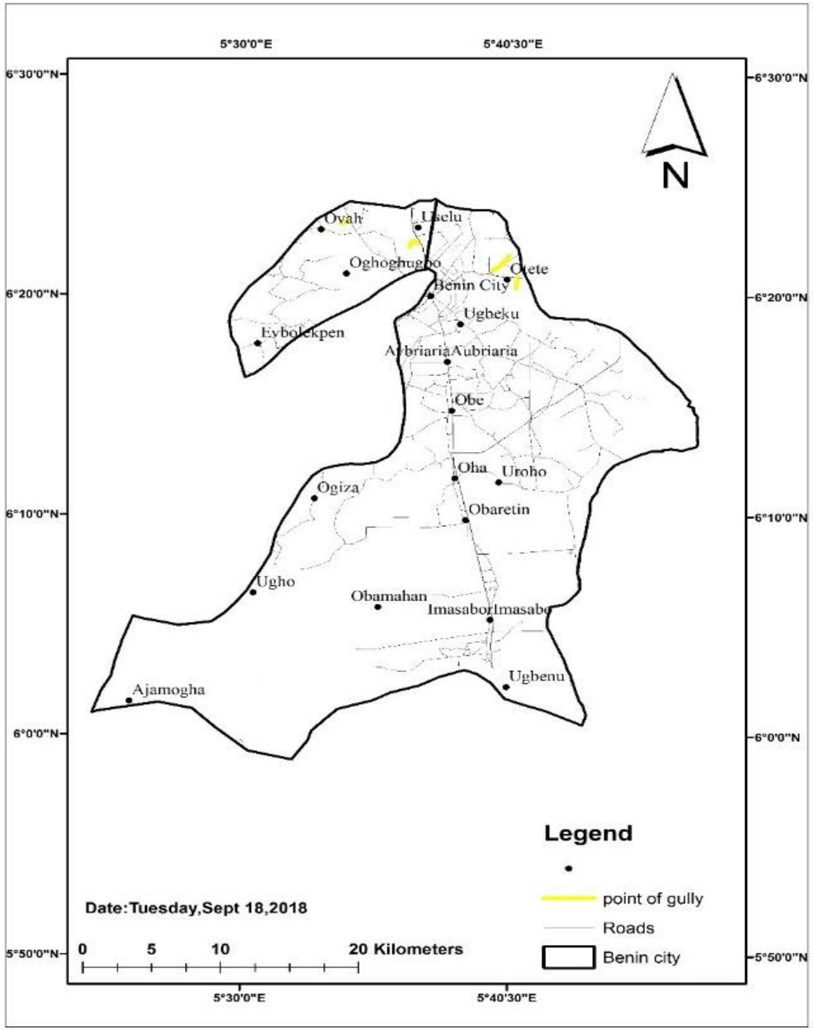
CI=? -n/n-1= 0.07

RI = 1.12

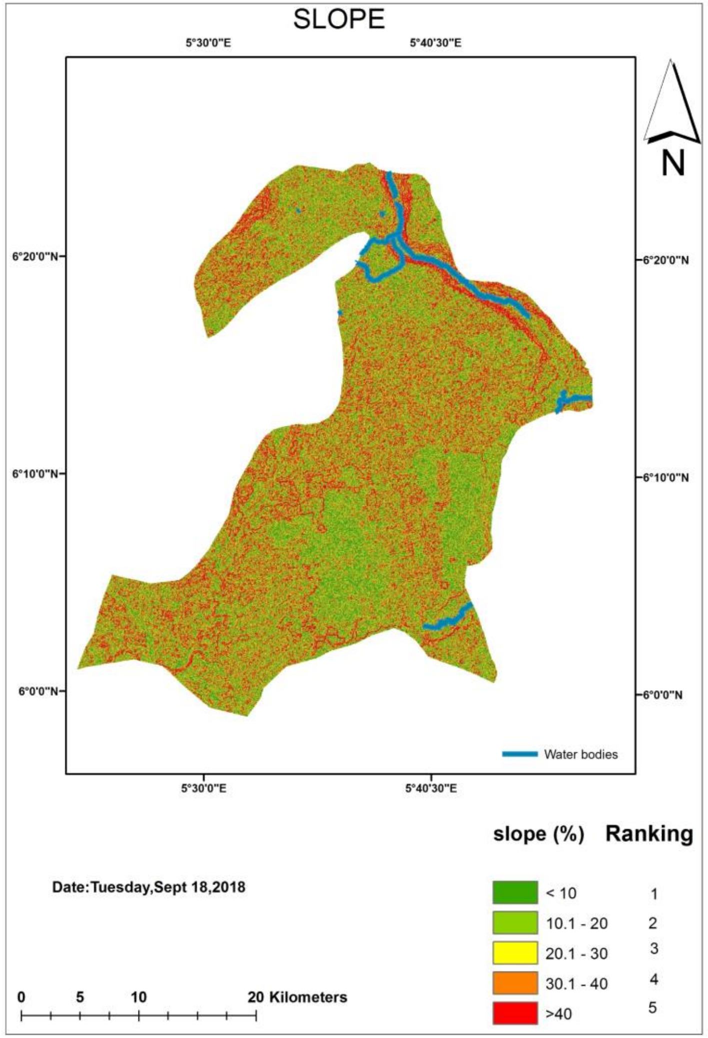
Consistency Ratio= 0.07

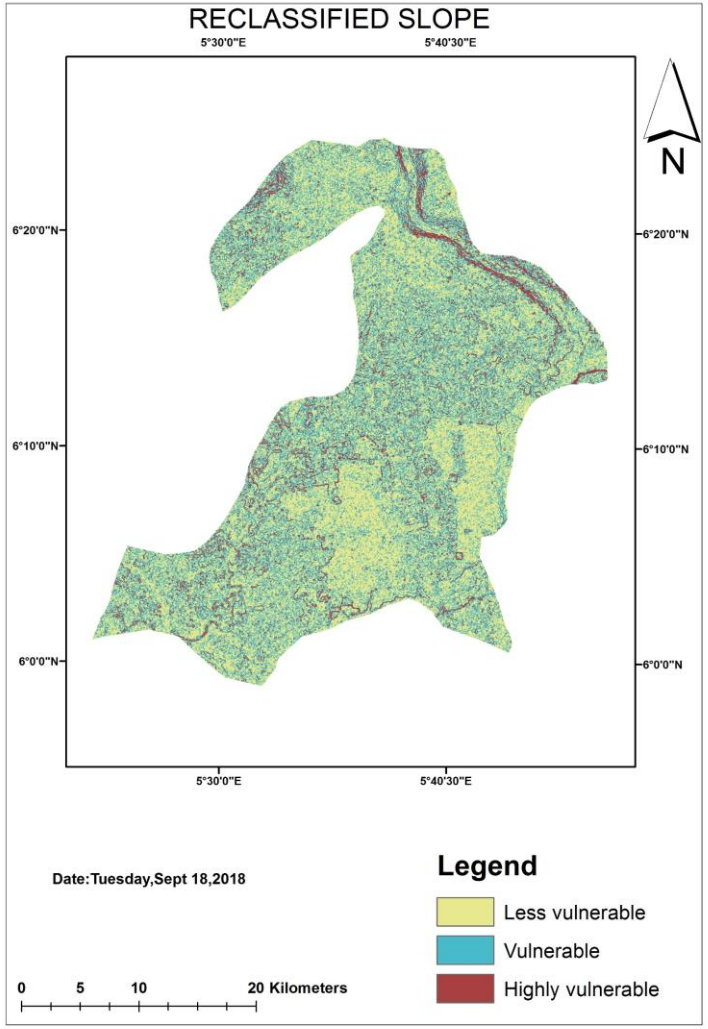
DETERMINE THE SPATIAL NATURE OF EXISTING GULLY EROSION

- With the help of handheld GPS, geographic coordinates were obtained to validate areas of gully erosion and later imported in GIS to show the spatial distribution of gullies in the area.

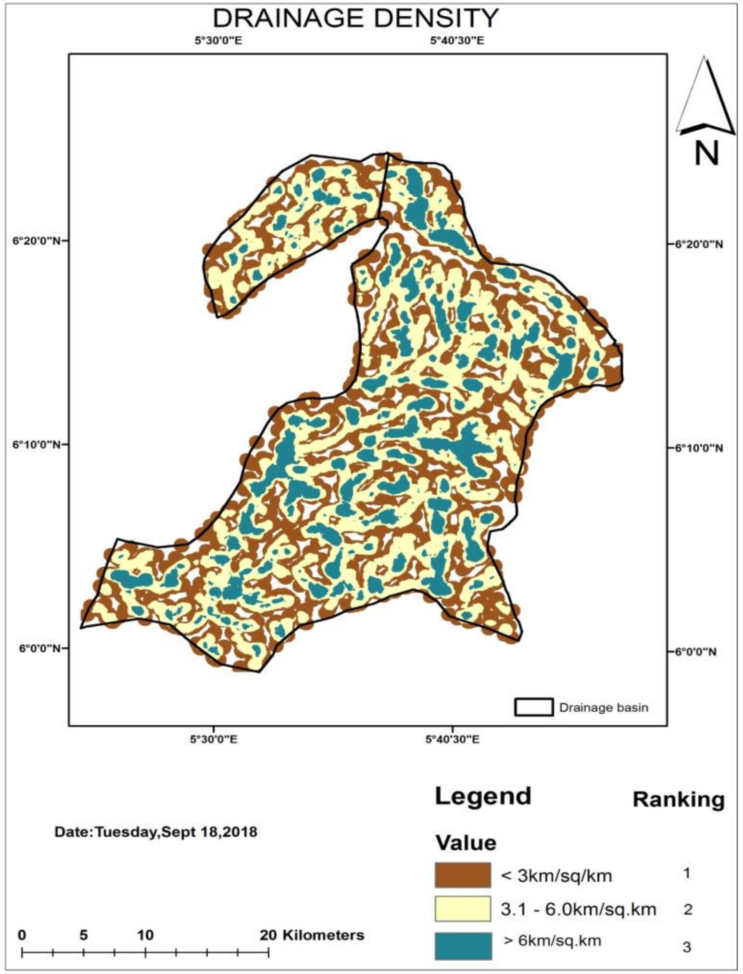


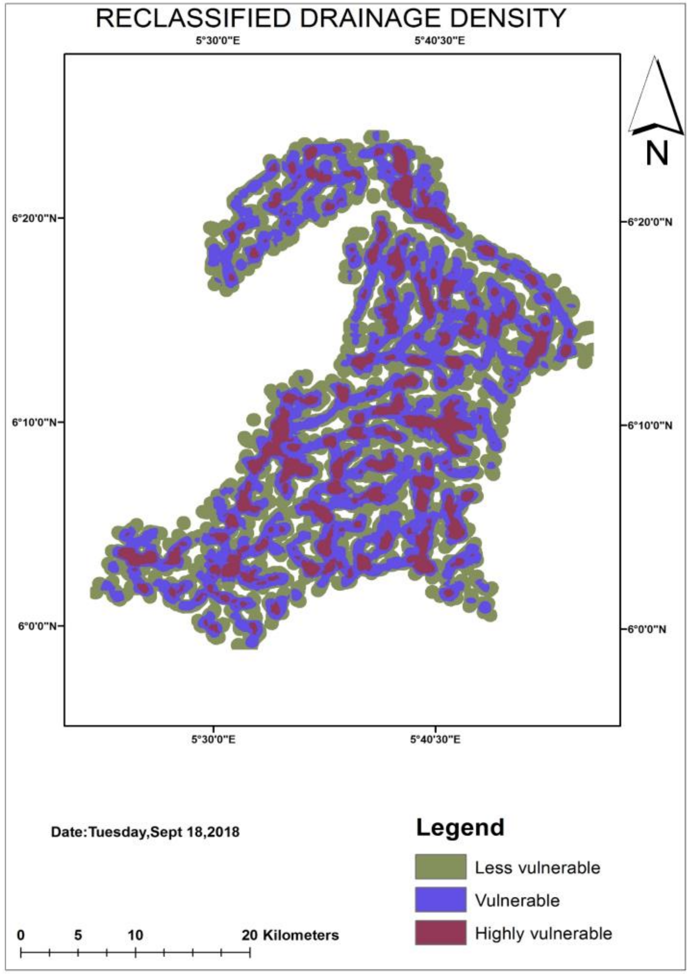
➢Slope plays a major role in gully erosion control. Generally, the steeper the slope, the higher the chance of gully erosion occurrence. The slope map was derived from DEM and the slopes were grouped in five classes: 0° -10°, 10° -20°, 20° -30°, 30° -40°, >40°



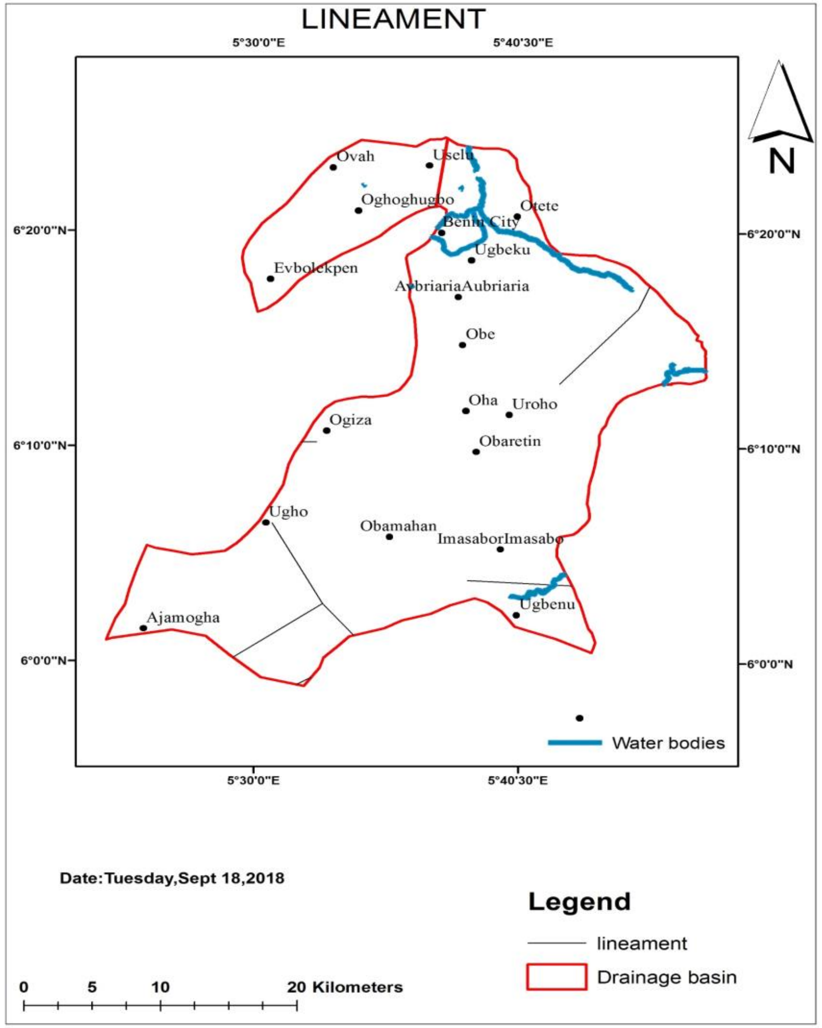


➢ It can be summarized that the length of streams and channels in an area can also be considered as an index to describe soil erodibility. The digital elevation model (DEM) was used to create the drainage pattern. The drainage density map was prepared after calculating the density of each cell divided by the total area of the basin.

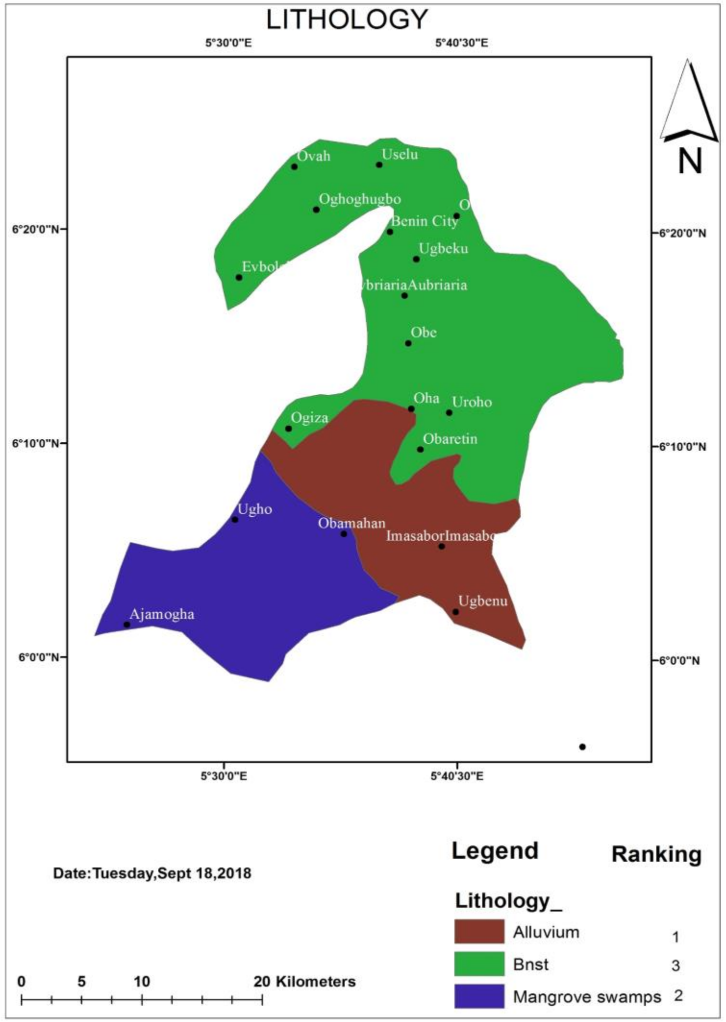


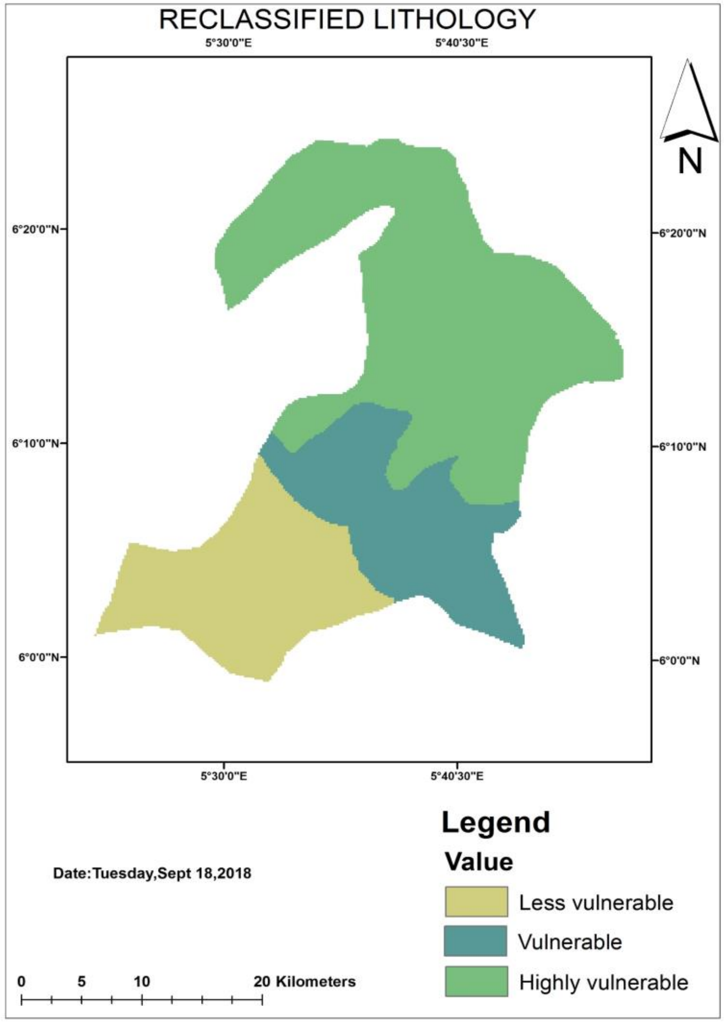


➢ The type of fracture also affects the gully erosion risk. The geology map was downloaded as a raster file. Pci geomatical software was used to extract lineament from the geology raster. The lineament was then reclassified in ArcMap into sub-classes.

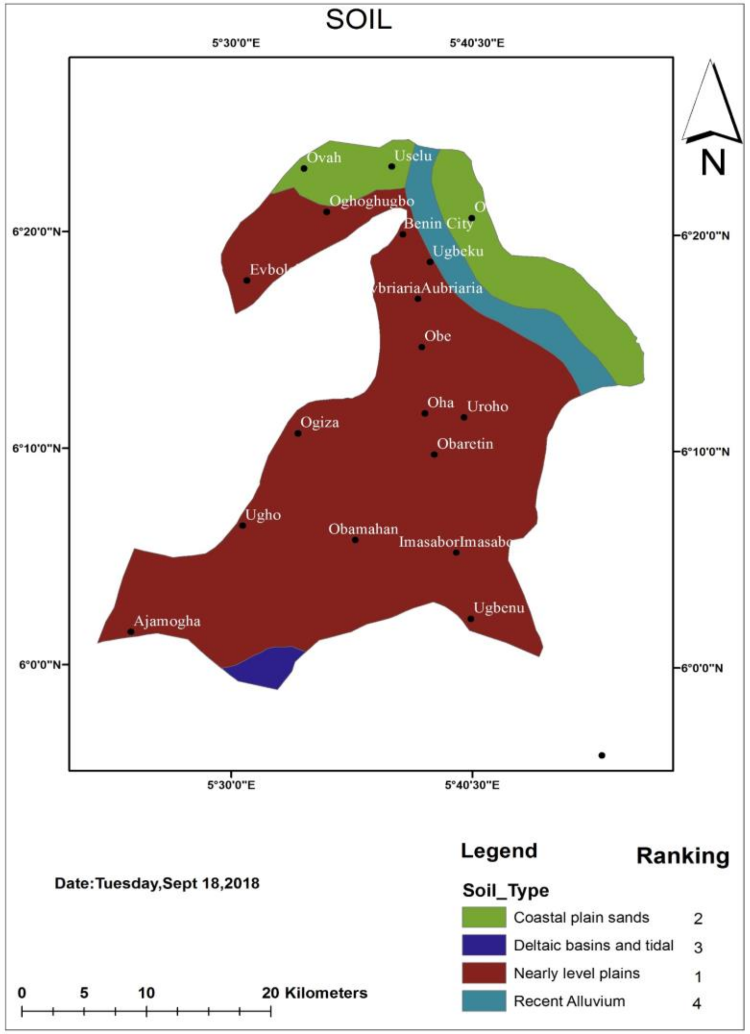


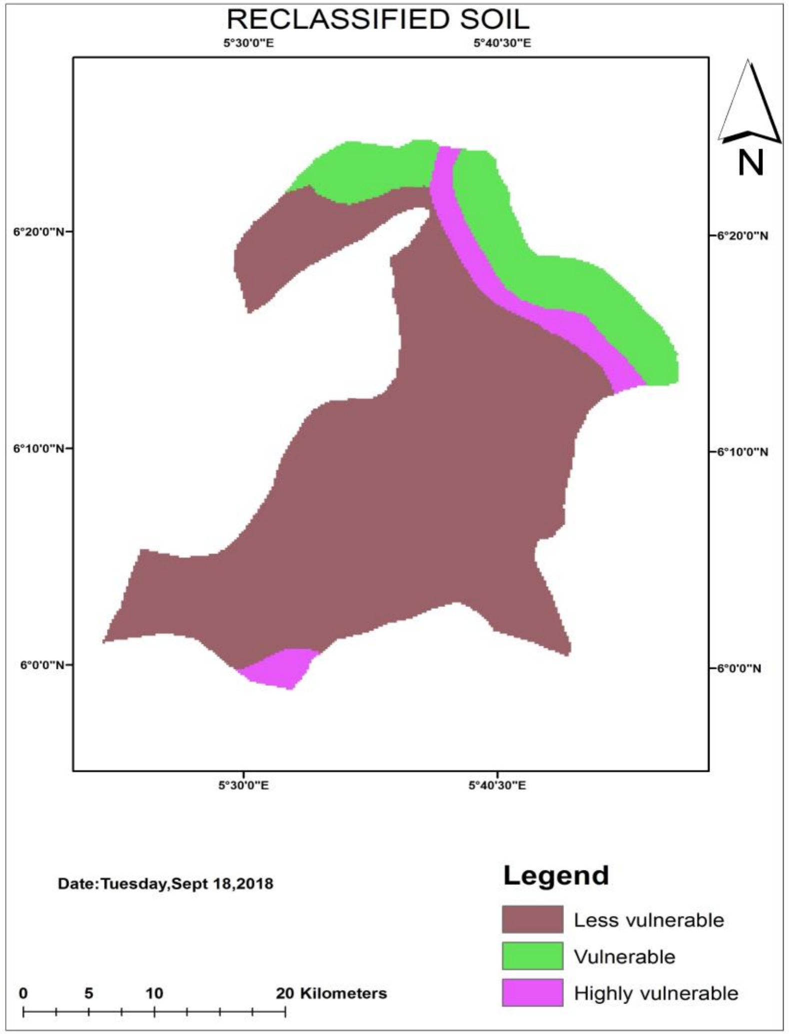
➢The type of rock can also affect gully erosion risk. The rock type and the structural state of rock types have important influence on the gully erosion process. The lithology map obtained from NGSA was used to extract various rock types that affect gully erosion differentially.



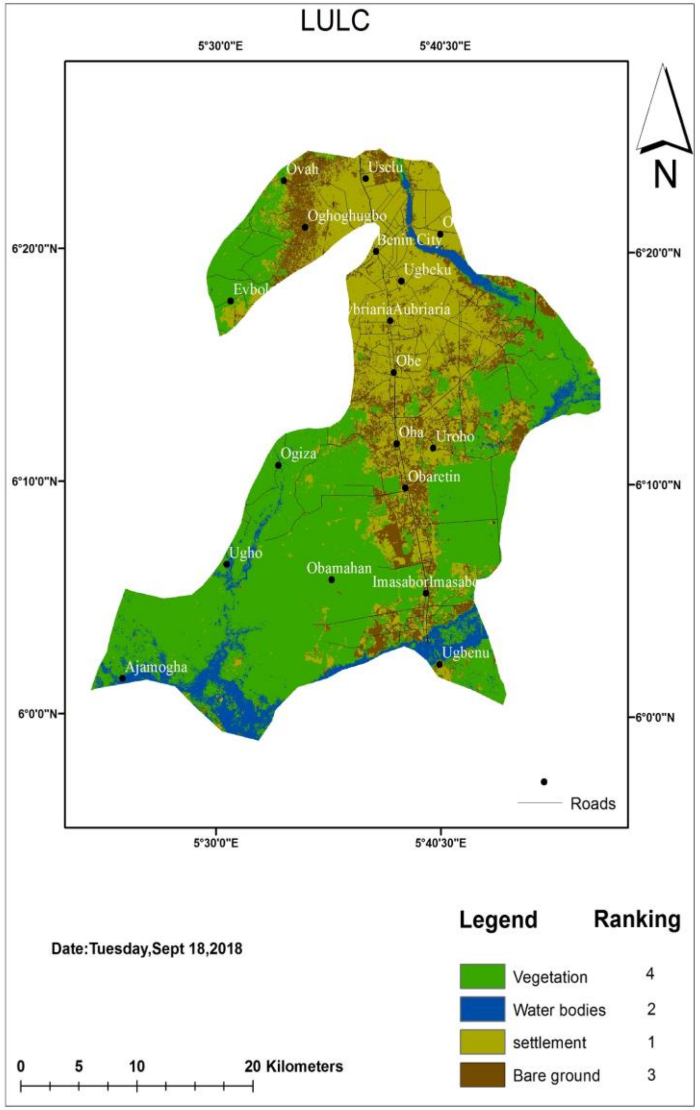


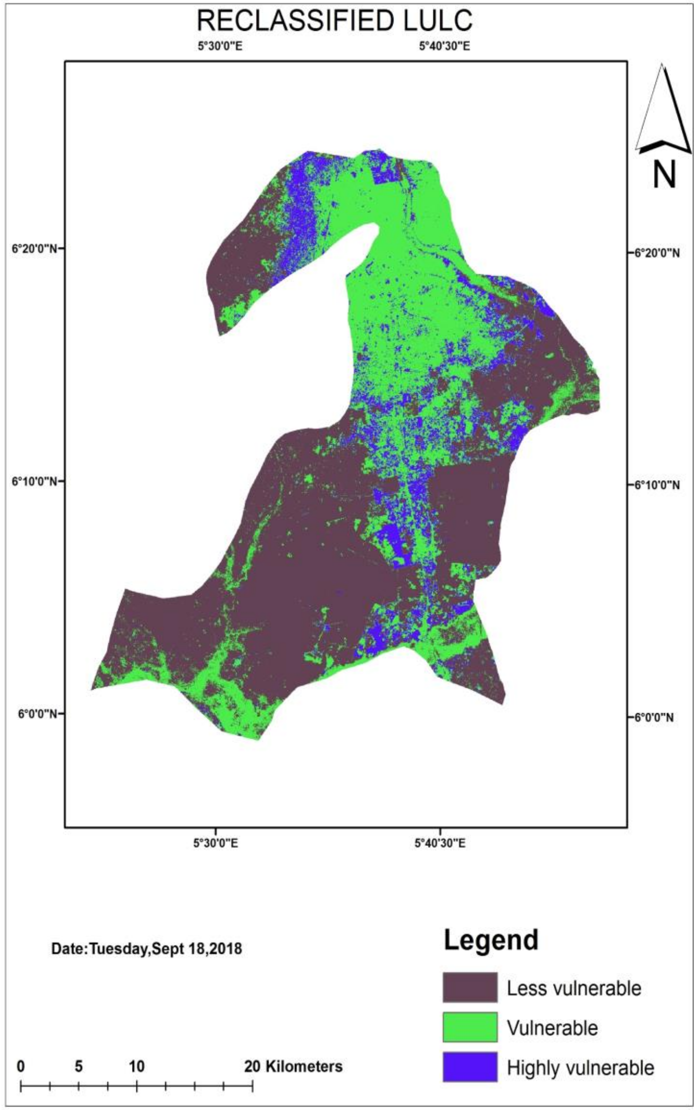
➢Soil map was ranked according to the infiltration/retaining characteristics of the soil type. The zone in the study area having soil with low retaining property produced high runoff causing high soil erosion.





- Different land use types in terms of area, size, features and pattern influences the occurrence of gully erosion. Landsat 8 (OLI) was downloaded from USGS



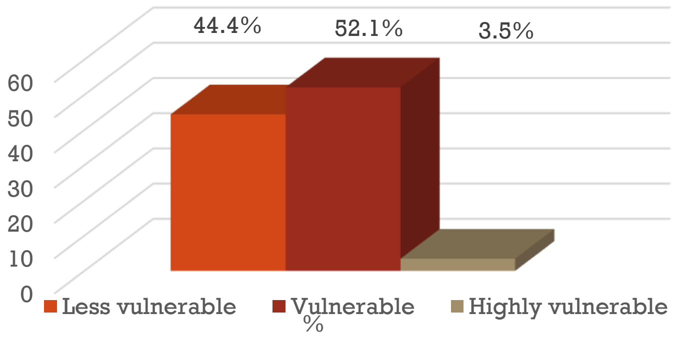


- Thus, result will be determined on the combination of all the causative factors. All the rating classes will be multiplied by their weights calculated using AHP method. This weight is a relative percent-age, and the sum of the percentage influence weights for all the raster maps will be equal to 100. Ranks are assigned as shown in Table Below.

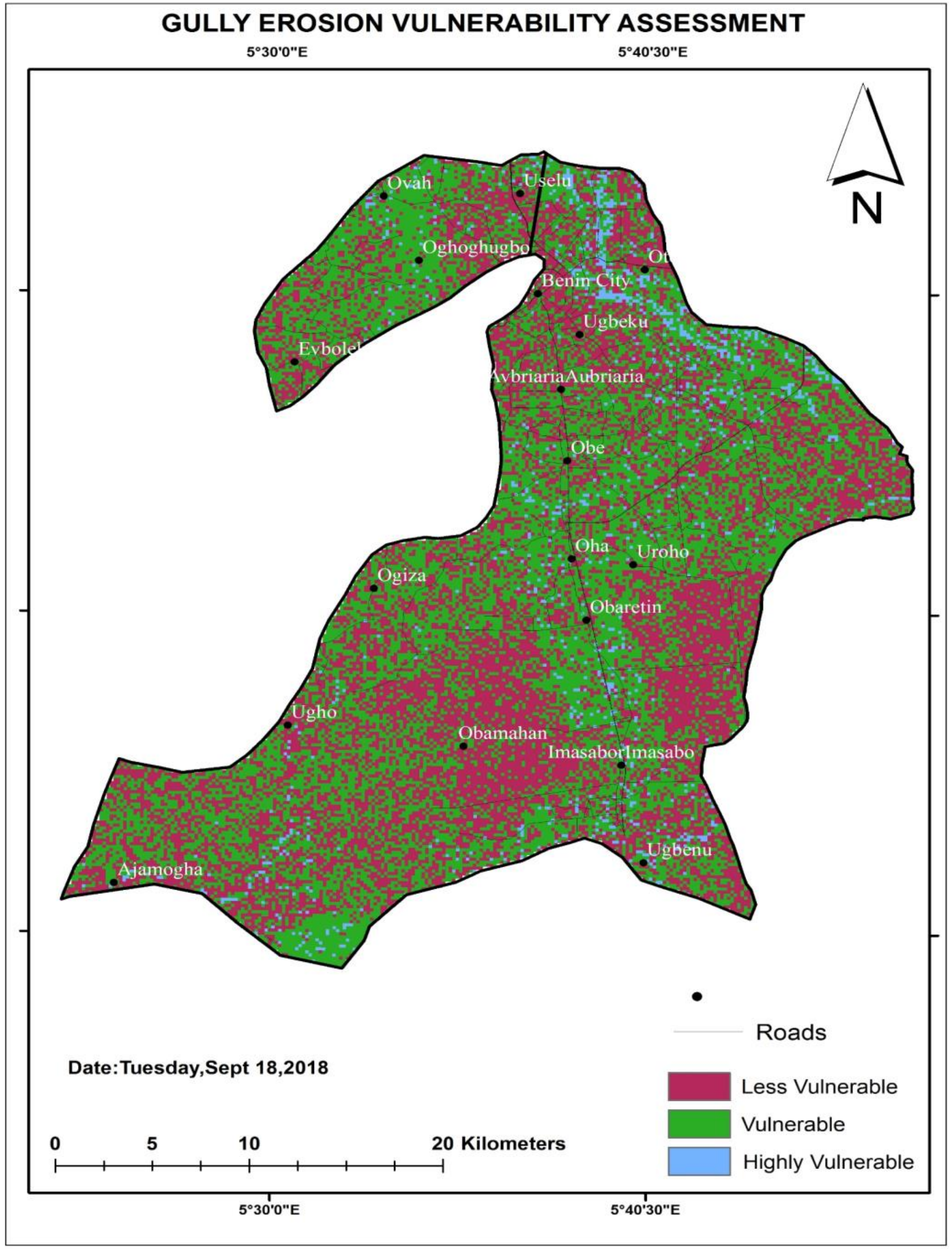
Gully Erosion parameters	Sub-class parameters	ranking
Land use/landcover	Vegetation	4
	Water bodies	2
	Settlement	1
	Bare ground	3
Lithology	Alluvium	1
	Benin formation	3
	Mangrove swamps	2
slope	<10%	1
	10.1 – 20%	2
	20.1 – 30%	3
	30.1 – 40%	4
	>40%	5
soil	Coastal plain sands	2
	Deltaic basins and tidal	3
	Nearly level plains	1
	Recent alluvium	4
Drainage density	< 3km/sq.km	1
	– 6.0km/sq.km	2
	>6km/sq.km	3

Ranking of Influencing Factors and their Sub-Classes

- Based on AHP method, weights are calculated as 50.0%, 26.2%, 13.5%, 6.8%, 3.5% respectively for land use/land cover, lithology, soils, slope and drainage density of the catchment and consistency ratio (CR) is found as 0.07. This indicated a reasonable level of consistency in the pairwise comparison of the factors.



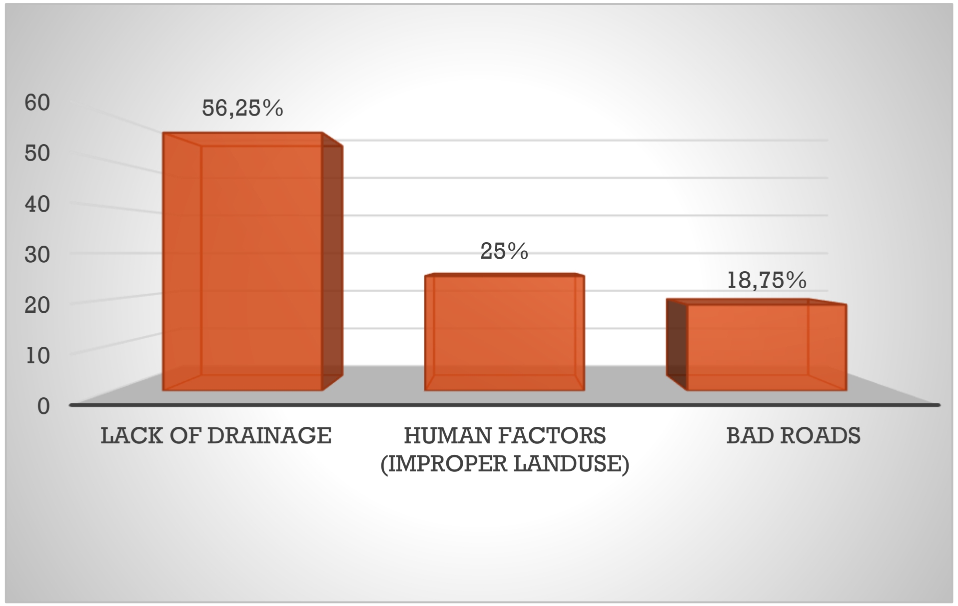
Value	Areas (sqm)	%
Less Vulnerable	416714800	44.4
Vulnerable	488688100	52.1
Highly Vulnerable	32366500	3.4
total	937769400	100



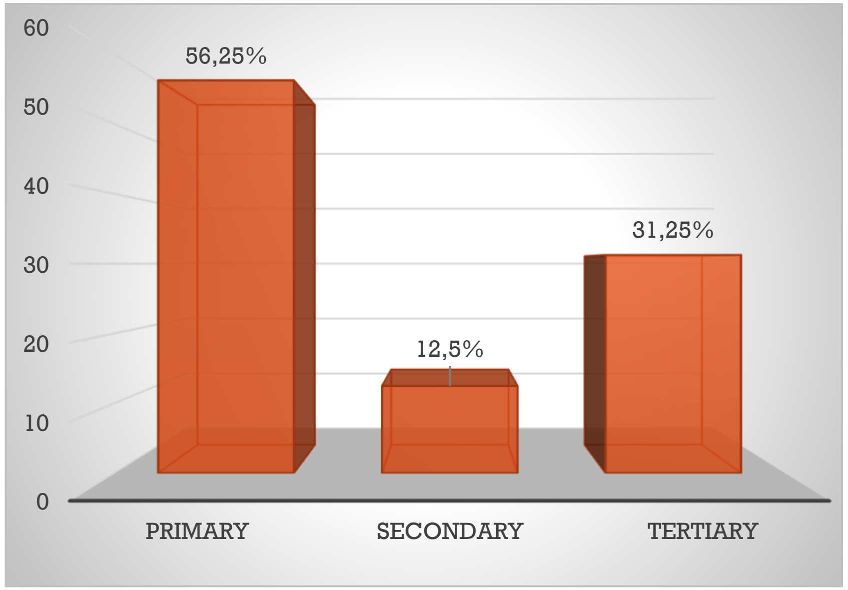
PERCEPTION OF PEOPLE TO GULLY EROSION USING QUESTIONNAIRE

- The major contributing factor that leads to the gully erosion formation are lack of drainage system (56.25%) human factors (improper land use practice-25%) and bad road construction(18.75%)as obtained from administered questionnaire.

- The figures show that 56.25% of the respondents obtained primary education, 12.5% obtained secondary school education while 31.25% attended tertiary institution.



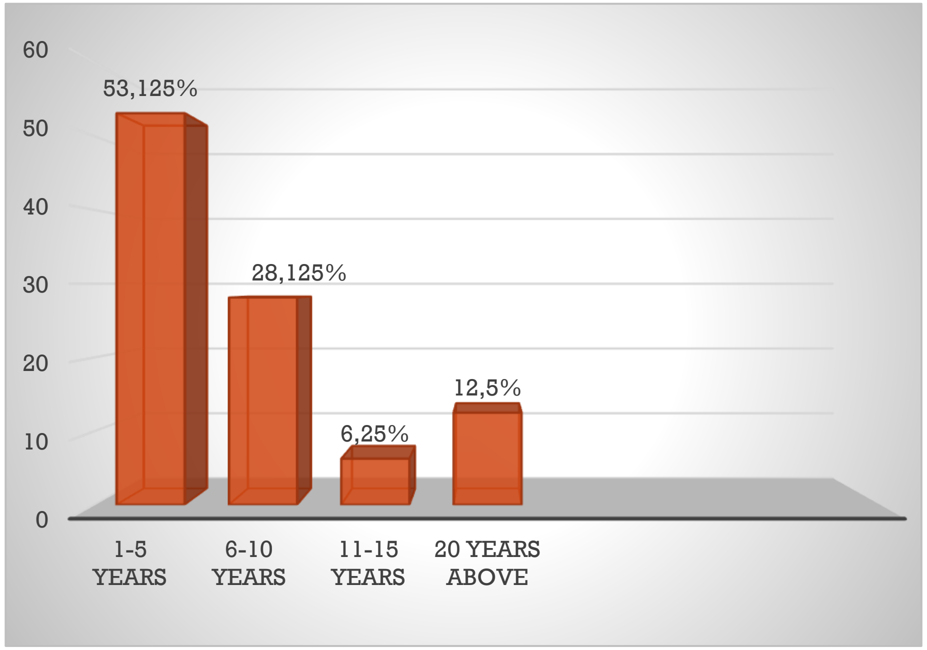
Factors that contribute to the development of gully erosion in the study area



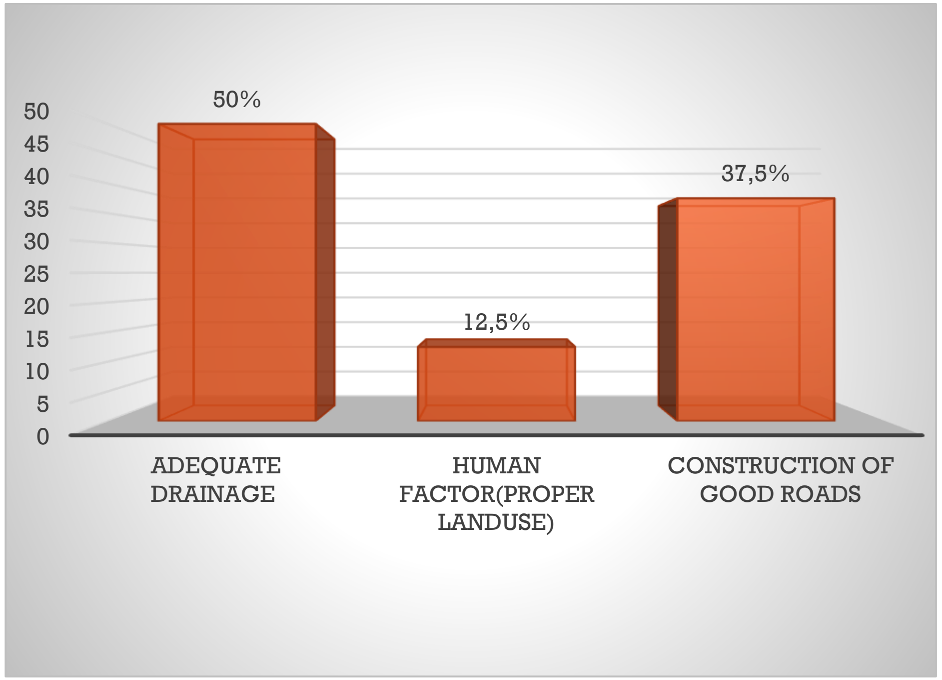
Educational status of respondents in Benin City, Nigeria

- 53.125% of the respondents have stayed 1-5 years in the study area, 28.125% of the respondents have stayed 6-10 years, 6.25% of the respondents have stayed 11-15 years and 12.5% of the respondents have stayed 20 years and above.

- The necessary control measure of gully erosion in the study area by the respondents includes; adequate Drainage (50%), Human factors (proper land use practice - 12.5%) and construction of good roads (37.5%)



Duration of stay of respondents in the study area



Control measures of gully erosion by the respondents

DISCUSSION

- About 3.5 percent of the total area was found highly vulnerable to gully erosion, around 52.1 percent of the total study area was found vulnerable to gully erosion and 44.4 per cent of the total area was less vulnerable to gully erosion. The gully erosion vulnerability map shown above is strongly related with slope and soil, which was expected due to highest weighting being given to them.

- Based on the analysis and the result obtained from this research as interpreted from the satellite imageries of the gullies in Benin city and questionnaires, the area vulnerable to gully erosion will increase over time with result from the research.

- The respondents have the correct perception by showing that the major causes of gully erosion are lack of drainage, the drainage are inadequate to properly channel water, the water then finds it way thereby creating its channels which later develop to gullies.

CONCLUSIONS

- Benin city is facing serious environmental threat as a result of gully erosion such as, inaccessible roads to some areas within the study area, as such some residence living close the gully have abandoned their building. Proper steps such as timely control of sheet and rill erosion should be taken before it develops into gully erosion to prevent further environment degradation resulting to gully erosion.

- This study therefore shows how critical the problem of gully erosion in the area is and makes a clarion call on Edo state government and other ecological foundations to act quickly to remedy the situation, preserve the environment and reduce/eliminate the vulnerability of inhabitants of the study area to gully erosion, by treating the geo-environmental hazards of gullies in Benin City.

✓THANK YOU……